10.48047/jocaaa.2025.34.12.84

EXPLICIT DYNAMIC ANALYSIS FOR IMPROVING AUTOMOTIVE BODY SAFETY AND STRUCTURAL INTEGRITY

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Received: 20.10.2025 Revised: 30.11.2025 Accepted: 21.12.2025

ABSTRACT

Reducing the mass of automotive structures while maintaining safety and structural integrity is a key challenge in modern vehicle engineering. Lightweight vehicle design improves fuel efficiency, performance, and emission control, but must not compromise crashworthiness. Recent advancements in high-performance composite materials have enabled the replacement of conventional metallic components with lightweight alternatives offering superior mechanical and energy-absorption characteristics. In this study, a complete automotive body structure is modeled using CATIA V5 and analyzed under frontal crash conditions using explicit dynamic finite element analysis in ANSYS Workbench. A comparative crashworthiness evaluation is carried out for AA7075-T651 aluminum alloy, stainless steel, and T300 carbon fiber composite to identify the most efficient material for lightweight vehicle body design. Key crash response parameters, including equivalent (von Mises) stress, total deformation, and energy absorption, are extracted and compared. A mass optimization strategy is also implemented to minimize the overall structural weight without compromising stiffness and durability. The results demonstrate that T300 carbon fiber composite provides the highest stiffness-to-weight ratio, significant mass reduction, and superior energy-absorption capability compared to metallic materials. This confirms the effectiveness of CAE-based explicit dynamic analysis in the development of lightweight, safe, and high-performance automotive body structures.

1.INTRODUCTION

An automobile is a four-wheeled vehicle designed for safe passenger transport. Modern automotive design emphasizes fuel efficiency, safety, and performance, making weight reduction a critical goal. Lightweight materials such as aluminum alloys, magnesium, and fiber-reinforced composites are increasingly used due to their high strength-to-weight ratio and superior energy absorption. Crashworthiness, the ability of a structure to absorb impact energy while protecting occupants, is a key design parameter. Full-scale crash testing is costly and time-consuming; hence, CAE and explicit dynamic FEA enable accurate virtual evaluation of vehicle structures. This study evaluates the crash performance of an automotive body using AA7075-T651 aluminum, stainless steel, and T300 carbon fiber composite to

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identify the material that offers optimal weight reduction without compromising safety.

2.REVIEW OF LITERATURE

Many researchers have investigated methods to improve vehicle crashworthiness while reducing overall weight. Finite element modeling is widely used to simulate vehicle crashes because it provides accurate predictions of deformation, stress, and energy absorption. Hickey and Shaoping [1] showed that FEM-based crash simulations can effectively replace expensive physical crash tests while maintaining high accuracy. Lin et al. [5] and Muhammad [8] also confirmed the reliability of explicit dynamic analysis in ANSYS for predicting vehicle crash behavior.

Lightweight materials play a major role in modern automotive design. Ahmad [2] reported that carbon fiber composites provide high strength and stiffness with very low weight, enabling large reductions in vehicle mass. Santhakumar [3] demonstrated that FRP-based vehicle bodies can achieve 60–70% weight reduction while improving crash energy absorption. Praveen and Sandeep Kumar [9] further noted that aluminum, magnesium, and composite materials improve fuel efficiency but must be carefully evaluated due to their limited ductility during impact. Several studies have focused on specific crash scenarios and vehicle components. Narender [6] investigated aluminum bumper beam systems and showed that they reduce vehicle weight while meeting safety requirements. Byeong Sam [10] performed LS-DYNA-based frontal crash simulations and found that the front structure absorbs most of the crash energy. Steven Jones [4] analyzed side-impact crashes and concluded that driver behavior influences crash severity, although no structural material comparison was included.

3.METHODOLOGY OF INVESTIGATION

3.1 Aim

The aim of this study is to design and analyze an automotive body using CATIA V5 and ANSYS Workbench to evaluate crashworthiness and identify the most suitable lightweight material. AA7075-T651 aluminum, stainless steel, and T300 carbon fiber composite are compared for stress, deformation, and energy absorption to determine the optimal balance of weight reduction and structural safety.

3.2 Scope of the Project

The study evaluates frontal crash behavior of an automotive body using AA7075 aluminum, stainless steel, and T300 carbon fiber, analyzing stress, deformation, and energy absorption to identify the material that ensures maximum strength with minimum weight.

3.3 Load Calculation for Your Automotive Crash Analysis

A passenger vehicle of mass **1200 kg** is subjected to a **frontal crash** at a speed of **60 km/h** against a rigid wall. The stopping distance during the crash is **0.6 m**. Determine the **impact force**, **deceleration**, and **stress basis** used for crash analysis in **ANSYS**.

Given Data

- Vehicle mass, $m = 1200\,\mathrm{kg}$
- Vehicle speed, $v = 60\,\mathrm{km/h} = 16.67\,\mathrm{m/s}$
- Stopping distance, $d = 0.6\,\mathrm{m}$

Step 1: Kinetic Energy of the Vehicle

$$KE = \frac{1}{2}mv^2$$

$$KE = \frac{1}{2} \times 1200 \times (16.67)^2$$

$$KE = 166{,}668\,\mathrm{J}$$

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Step 2: Equivalent Impact Force

The equivalent static force corresponding to the crash energy is:

$$F = \frac{KE}{d}$$

$$F = \frac{166{,}668}{0.6}$$

$$F = 277{,}780\,\mathrm{N} \approx 278\,\mathrm{kN}$$

Step 3: Vehicle Deceleration

$$a = \frac{v^2}{2d}$$

$$a = \frac{(16.67)^2}{2 \times 0.6}$$

$$a = 231.5\,\mathrm{m/s^2}$$

Deceleration in g-forces

$$g = \frac{a}{9.81} = \frac{231.5}{9.81} = 23.6\,g$$

Step 4: Pressure Applied on Vehicle Front

Assuming frontal impact area:

$$A = 0.30\,\mathrm{m^2}$$

$$P = \frac{F}{A}$$

$$P = \frac{277{,}780}{0.30}$$

$$P = 925{,}933\,\mathrm{Pa} \approx 0.93\,\mathrm{MPa}$$

Step 5: Stress Calculation Basis

Equivalent (Von-Mises) stress is computed as:

$$\sigma_v = \sqrt{\frac{1}{2}\left[(\sigma_1-\sigma_2)^2 + (\sigma_2-\sigma_3)^2 + (\sigma_3-\sigma_1)^2\right]}$$

ANSYS automatically calculates this value from the applied loads and boundary conditions.

4.MODELING, MESHING, SELECTION OF MATERIALS AND METHODS

4.1 METHODOLOGY

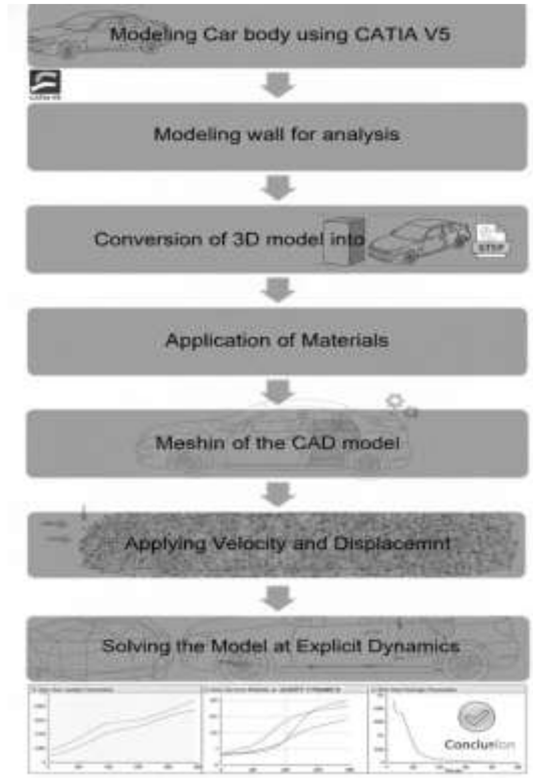

Fig. 4.1 Methodology of Design and Crash Analysis of Car Body Structure

4.3 Material Selection

Based on these requirements, three materials

Stainless Steel,

AA7075-T651

Aluminum Alloy,

T300 Carbon Fiber Composite

selected for comparative crashworthiness analysis in this study to determine the most suitable material for lightweight and safe automotive body structures.

4.4.1 Car Body Structure Modeling

Table 4.4 Dimensions of the Car Body Structure

Parameter	Dimension	Unit
Length	4395	mm
Width	1905	mm
Height	1400	mm

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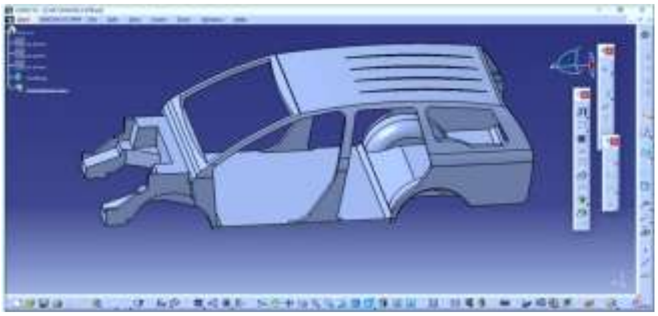

Fig: 4.2 Modellings of the car body structure

Fig: 4.4 Detailed drawings of the car body

4.4.2 Creating a Rigid Wall for Crash Analysis

Table 4.5 Dimensions of the Rigid Wall

Parameter	Dimension	Unit
Length	3000	mm
Height	2000	mm
Thickness	200	mm

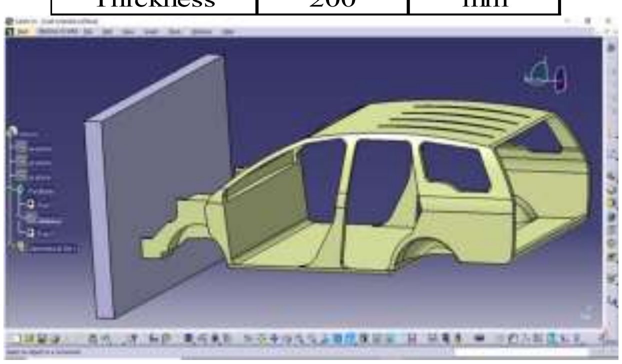

Fig. 4.5 Modeling of the Rigid Wall

4.5.2 Meshing

Table 4.6 Mesh Settings for Car Body and Wall

Total Nodes	37,741
Total Elements	161,798

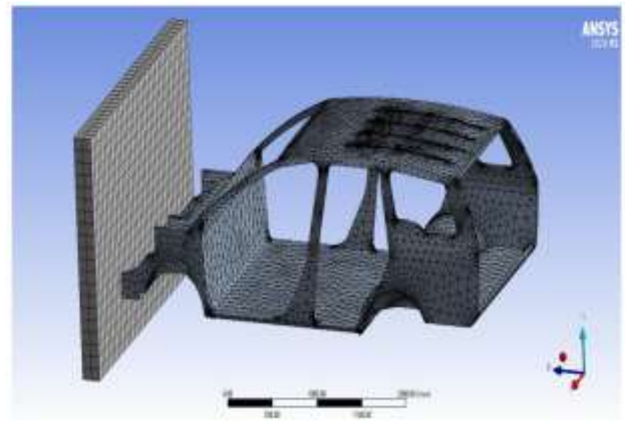

Fig. 4.6 Meshed 3D Model of Car Body and Wall

4.5.3 Boundary Conditions

The car body is given a frontal velocity of 100 km/h toward a fixed rigid wall. The wall is fully constrained, and all node degrees of freedom are properly restricted to simulate realistic crash behavior, allowing evaluation of stress, deformation, and energy absorption.

Table 4.7 Velocity Settings for Crash Analysis

Parameter	Value
Input Type	Velocity
Defined By	Components
Coordinate System	Global Coordinate System
X Component	0 mm/s
Y Component	0 mm/s
Z Component	27,778 mm/s

Displacement constraints control the motion of nodes or components during simulation. In this study, constraints are applied to the car body and rigid wall to replicate frontal crash conditions. They enable calculation of equivalent (von Mises) stress and total deformation for stainless steel, AA7075 aluminum, and T300 carbon fiber, supporting evaluation of crashworthiness and structural performance.

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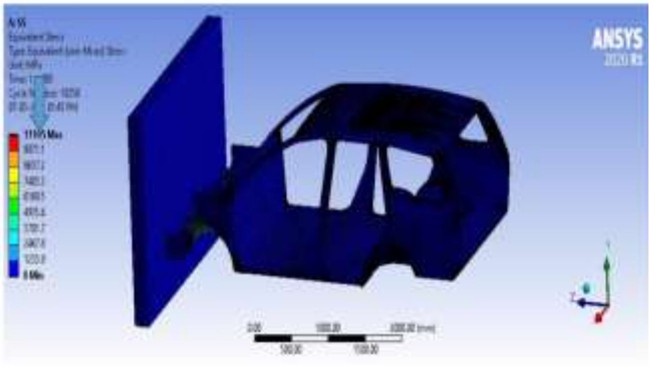


4.5.4 Analysis of Stainless Steel Car Body

Stainless steel shows 1105 MPa stress and 36.3 mm deformation, indicating high strength and moderate deformation. Results will be compared with aluminum and carbon fiber to find the best balance of crashworthiness and weight.

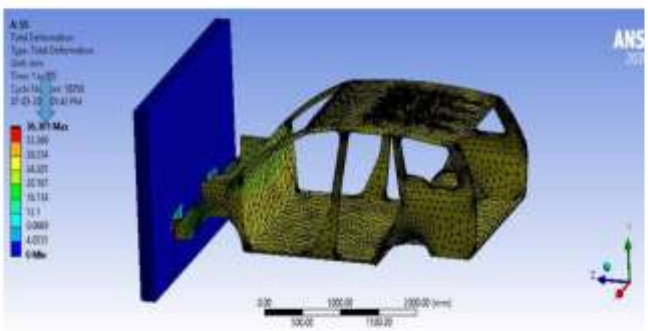


Fig. 4.10 Equivalent Stress Distribution for Stainless Steel Car Body

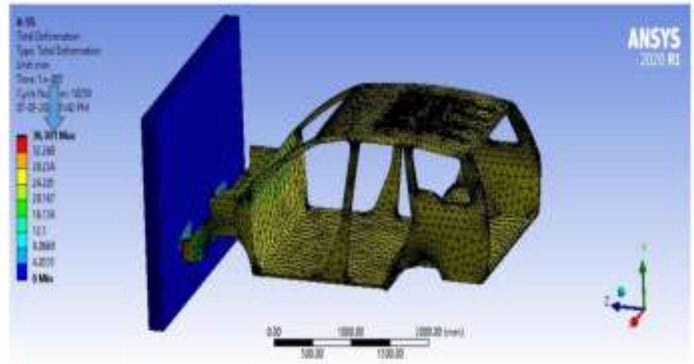
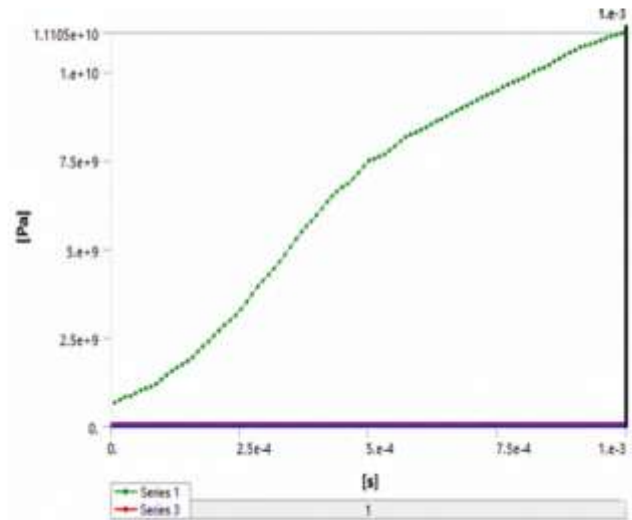
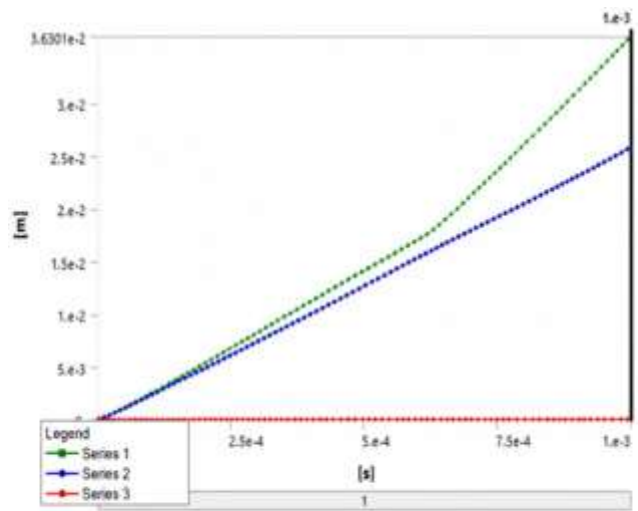


Fig. 4.11 Total Deformation of Stainless Steel Car Body



Graph 4.1 Equivalent Stress for Stainless Steel Car Body



Graph 4.2 Total Deformation of Stainless Steel Car Body

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4.5.5 Analysis of AA7075-T651 Aluminum Car Body

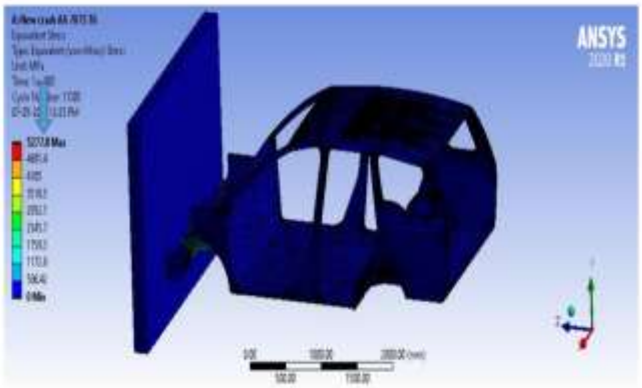


Fig. 4.12 Equivalent Stress Distribution for AA7075-T651 Aluminum Car Body

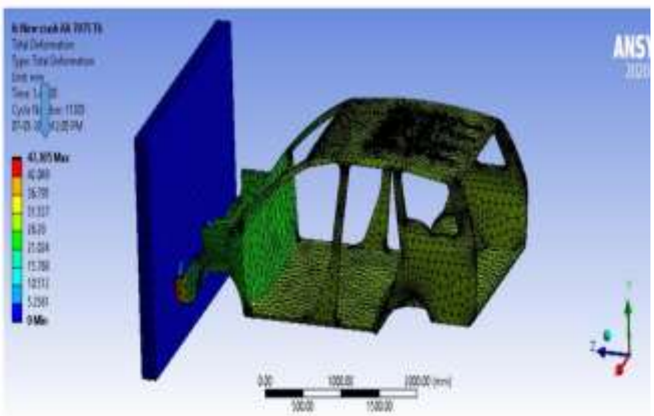
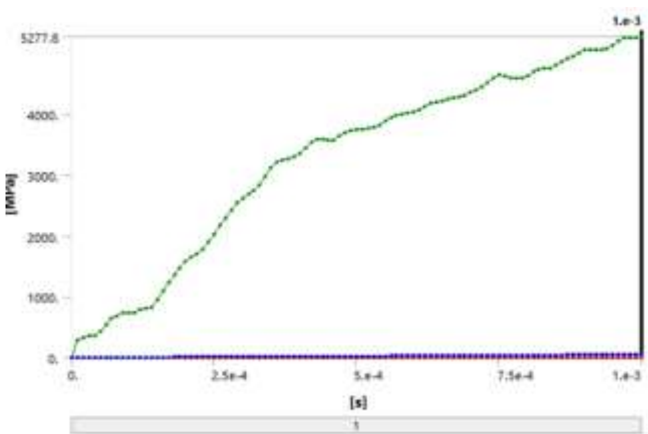
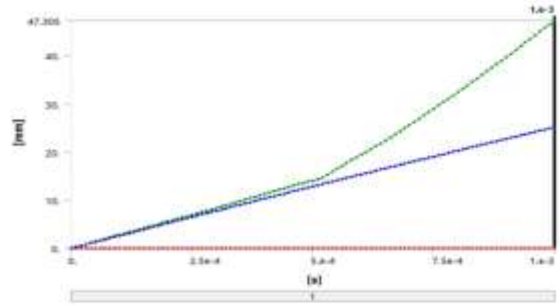


Fig. 4.13 Total Deformation of AA7075-T651 Aluminum Car Body



Graph 4.3 Equivalent Stress of AA7075-T651 Aluminum Car Body



Graph 4.4 Total Deformation of AA7075-T651 Aluminum Car Body

4.5.6 Analysis of T300 Carbon Fibre Composite Car Body

The T300 carbon fiber composite is evaluated as a lightweight alternative to stainless steel and AA7075 aluminum using explicit dynamic crash simulation in ANSYS Workbench. The car body is assigned T300 properties, with the same 100 km/h velocity and boundary conditions applied for consistency.

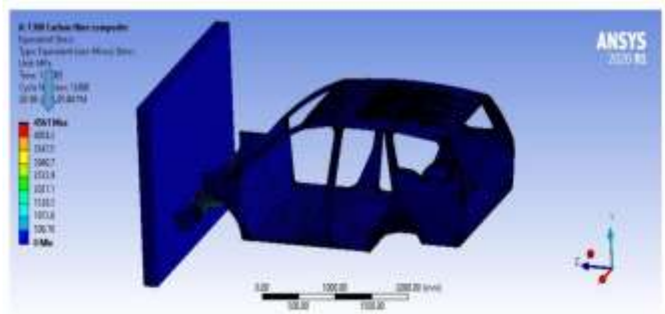


Fig. 4.14 Equivalent Stress Distribution for T300 Carbon Fibre Composite Car Body

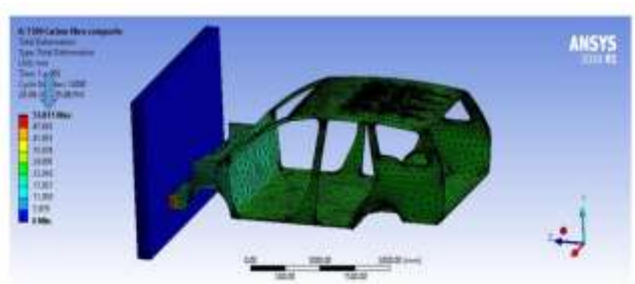


Fig. 4.15 Total Deformation of T300 Carbon Fibre Composite Car Body

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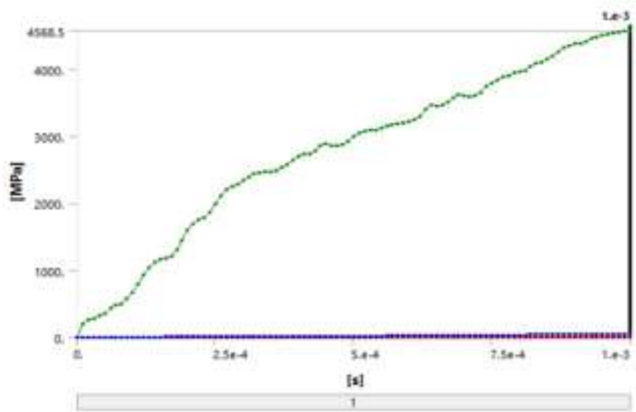
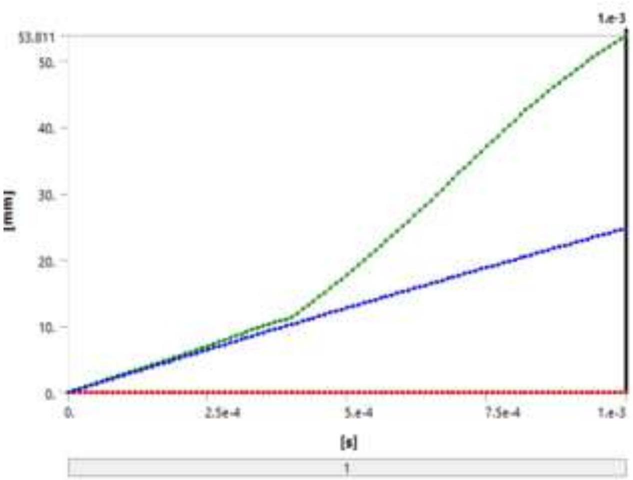


Graph 4.5 Equivalent Stress of T300 Carbon Fibre Composite Car Body



Graph 4.6 Total Deformation of T300 Carbon Fibre Composite Car Body

5. RESULTS AND DISCUSSION

Table 5.1: Crash Analysis Results of Car Body for Different Materials

Material	Velocity (m/s)	Equivalent Stress (MPa)	Total Deformation (mm)
Stainless Steel	27.78	1207	46.301
AA7075-T651 Aluminum	27.78	628.8	47.305
T300 Carbon Fibre Composite	27.78	5561	63.811

- Stainless Steel: High stress, low deformation; very strong but heavy.
- AA7075 Aluminum: Moderate stress and deformation; good balance of weight and strength.
- T300 Carbon Fiber: High stress and maximum deformation; excellent energy absorption and strength-to-weight ratio.

Total deformation indicates how well each material absorbs impact energy to protect occupants.

Table 5.3: Total Deformation Comparison

Material	Total Deformation (mm)
Stainless Steel	46.301
AA7075-T651 Aluminum	47.305
T300 Carbon Fibre Composite	63.811

Observations:

1. Stainless steel exhibits the lowest total deformation (46.301 mm), indicating high rigidity and minimal displacement, but lower energy absorption.

2. AA7075-T651 aluminum shows moderate deformation (57.305 mm), providing a balance between lightweight design and structural strength.

T300 carbon fibre composite has the highest deformation (63.811 mm), demonstrating superior energy absorption capability and flexibility under impact, which is ideal for protecting passengers in a crash.

CONCLUSION

The crash analysis of the car body structure demonstrates that material selection plays a critical role in vehicle safety, performance, and efficiency. Among the three materials evaluated—stainless steel, AA7075-T651 aluminum alloy, and T300 carbon fiber composite—the results highlight the advantages of advanced lightweight materials over conventional steel. T300 carbon fiber composite exhibited the highest energy absorption and favorable equivalent stress, along with an extremely low weight of 410 kg, achieving maximum strength with

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minimum mass. This makes it the most suitable material for high-performance, lightweight, and crash-safe automotive body structures. AA7075 aluminum alloy also showed good performance, providing a balanced combination of strength, deformation, and reduced mass, making it a practical alternative for modern vehicle design. In contrast, stainless steel, despite its high rigidity, is heavier and absorbs less impact energy, limiting its suitability for fuel-efficient and crash-safe vehicles. Overall, the study establishes that carbon fiber composites and high-strength aluminum alloys significantly improve crashworthiness, reduce vehicle weight, and enhance occupant safety, with T300 carbon fiber emerging as the optimal choice for future automotive applications.

FUTURE SCOPE

Future work can include side, rear, rollover, and offset crash analyses, optimization of carbon-fiber lay-ups, hybrid material structures, fatigue and durability studies, integration of occupant safety systems, experimental validation, and application to electric vehicle bodies to improve safety and performance.

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